

## Motion into and out of the blind spot: evidence for spatial extrapolation of moving objects

Article (Published Version)

Maus, Gerrit and Nijhawan, Romi (2008) Motion into and out of the blind spot: evidence for spatial extrapolation of moving objects. *Perception*, 37 (2). p. 310. ISSN 0301-0066

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# Twelfth Applied Vision Association Christmas Meeting Aston University, Birmingham, UK 17 December 2007

## ABSTRACTS

### ◆ **Perceptual decisions and visual learning in the human brain**

- 1 Zoe Kourtzi (School of Psychology, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK; e-mail: z.kourtzi@bham.ac.uk)

In our everyday interactions we encounter a plethora of novel experiences in different social contexts that require prompt decisions for successful actions. Extracting the key features from our sensory experiences, assigning them to meaningful categories, and deciding how to interpret them is a computationally challenging task that is far from understood. I discuss our recent behavioural and imaging work investigating the neural mechanisms that the human brain employs for solving perceptual and categorical decisions. I present findings demonstrating that learning shapes perceptual decisions and the mechanisms that mediate experience-dependent plasticity in the human brain. Finally, I provide novel evidence for flexible neural coding in the human brain that translates sensory experiences to categorical decisions by shaping neural representations across areas with dissociable roles in visual categorisation.

### ◆ **fMRI activity in human visual cortex correlates with perceptual judgments of 3-D shape**

- 2 Tim Preston, Zoe Kourtzi, Andrew E Welchman (School of Psychology, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK; e-mail: tjp541@bham.ac.uk)

The horizontal separation of the eyes produces a potent cue to depth in the form of binocular disparity. Electrophysiological and neuroimaging studies have shown that several regions of visual cortex are involved in the processing of disparity. However, the behavioural relevance of activity in these areas is not well understood. Here, we show that fMRI responses in higher dorsal and ventral visual areas correlate with observers' perceptual judgments of disparity-defined 3-D shape. We used line drawings of Mach card stimuli which were disambiguated by means of binocular disparity. We defined psychometric functions for observers ( $N = 6$ ) who judged the 3-D shape (convex or concave) of test stimuli containing differing amounts of disparity. When test stimuli were preceded by a brief concave or convex Mach card adaptor stimulus, the observers' judgments were biased away from the shape of the adaptor stimulus. We used an event-related fMRI adaptation paradigm to measure activity relating to this aftereffect in the visual cortex. fMRI responses for probe stimuli with the same shape as the adaptor decreased in dorsal (V3A, V3B/KO, V7, hMT+/V5) and ventral (VP/V3, V4, LO) visual areas. In contrast, we observed increased fMRI responses in these areas when the adaptor and probe stimuli differed in their 3-D shape. Consistent with the behavioural aftereffect we observed similar fMRI selective adaptation in these areas when the test stimulus itself contained no disparity information. These findings suggest that fMRI activity in higher visual areas relates to perceived 3-D structure, which is influenced by previous experience.

### ◆ **Perceptual learning for global contour integration**

- 3 D Samuel Schwarzkopf, Zoe Kourtzi (School of Psychology, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK; e-mail: D.S.Schwarzkopf@bham.ac.uk)

Recent computational work has suggested that the visual system is optimised for the analysis of statistical regularities that facilitate fast detection of contours. However, the role of experience in shaping these processes remains largely unknown. We tested whether learning facilitates the perceptual integration of contours embedded in noise. We compared the ability of observers to detect collinear contours defined by Gabor elements aligned along the contour path with contours defined by elements oriented orthogonally to the contour path (orthogonal contours). Specifically, observers were tested in a two-interval forced-choice task and judged which interval contained a contour. We observed an advantage in detection performance for collinear over orthogonal contours when embedded in a background of randomly oriented Gabor elements. Importantly, training to detect orthogonal contours (2200–4000 trials, over 3–5 daily sessions) resulted in improved performance. In particular, learning occurred after training with or without

feedback, and was specific to the trained contours. In contrast, detection of contours defined by elements aligned at an acute angle ( $30^\circ$ ) to the path remained poor. These findings suggest that learning strengthens the integration of elements oriented orthogonally to the contour path and improves our ability to detect contours in cluttered scenes. These findings provide evidence that the brain uses statistical regularities for the detection of targets in visual scenes and that this process is shaped by experience.

◆ **The combination of absolute and relative cues for location investigated using immersive virtual reality**

4 Ellen Svarverud, Stuart J Gilson<sup>¶</sup>, Andrew Glennerster (School of Psychology and Clinical Language Sciences, University of Reading, Earley Gate, Reading RG6 6AL, UK;

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In the absence of looming cues, observers ignore large changes in the size of a virtual scene around them and have large biases in size judgments as a result (Glennerster et al, 2006 *Current Biology* 16 428–432). At first sight, these results suggest that observers have poor access to information about absolute distance from stereo and motion parallax. However, we show here that under similar conditions observers have Weber fractions of 10% to 33% when asked to detect the expansion/contraction of the scene. In an immersive virtual-reality environment, subjects viewed a scene binocularly and with motion parallax from free head movement. They viewed a static scene which, after a blank ISI, changed size. The centre of expansion was the cyclopean point. The task was to identify whether the target object (and the rest of the scene) was closer or farther away in the second interval. These absolute thresholds were best when the object was close to the observer. We also measured thresholds for detecting changes in the location of an object relative to the scene, while its absolute distance remained constant. In a third experiment, subjects judged the relative distance of an object presented in each interval. The scene changed in size by a factor between 0.25 and 4. The pattern of biases in this experiment could be predicted from the thresholds measured in the first two experiments, suggesting that the observers do not have independent access to the individual cues.

◆ **The rotating-restaurant effect**

5 Peter A Howarth (Department of Human Sciences, Loughborough University, Loughborough LE11 3TU, UK; e-mail: p.a.howarth@lboro.ac.uk)

Retinal image movement can come about by movement of either the eye or the world, and veridical perception depends upon its correct interpretation. If the extra-ocular muscles move the eye, information is available to disambiguate the retinal image change, but if the head and whole body are being moved, it is not. Rotating restaurants provide a location in which the body moves steadily, but at a velocity below the threshold of the vestibular system. Viewing the 'join' between the rotating and stationary portions provides a large-field stimulus in which one part moves relative to the body, and the other does not. In these circumstances, one either experiences vection, or does not, depending upon which side of the 'join' one fixates, the sensation depending upon whether or not the point fixated is moving relative to one's body. A similar visual stimulus can be provided in the laboratory, and five participants each sat viewing a large ( $> 60^\circ$  V and H) bipartite field of random squares, with the upper portion moving horizontally and the lower portion stationary. All reported experiencing vection when fixating a (moving) point just above the join, but did not experience it to the same extent when fixating a (stationary) point just below the join. As previously reported, the sensation of vection varied over time; however, the changing of fixation, by a few centimetres, from a moving to a static (or vice versa) portion of the screen would generally change the sensation reported.

◆ **Colours, faces, and Mrs Thatcher's bikini**

6 Stuart Anstis (Department of Psychology, 0109 University of California at San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0109; e-mail: sanstis@ucsd.edu)

Some new(ish) illusions help to understand how we perceive colour, motion and faces.

*Colour and contours:* Achromatic test contours can materially alter the colours seen in afterimages. Following adaption to a single multi-coloured plaid, vertical black test lines can elicit afterimages of vertical blue/yellow stripes, while horizontal test lines can elicit afterimages, from the same adapting stimulus, of horizontal red/green stripes. Conclusion: the visual system averages colours within black/white test contours, and inhibits them laterally across contours.

*Colour combinations:* One eye viewed a digit '5' in red dots, hidden among green dots, like an Ishihara plate. The other eye viewed a digit '5' in green dots, hidden among red dots. When these were binocularly fused, the hue discrimination threshold was five times higher for two eyes than for one. So two eyes were worse than one.

**Motion:** Reversed phi and the Footsteps illusion reveal the role of luminance and contrast in motion perception. The Chopsticks and Sliding-Ring illusions demonstrate visual parsing of moving objects. The Flying Bluebottle measures simultaneous contrast in the motion domain, ie induced movement.

**Faces:** Upside-down and negative faces are both hard to recognise. I used a negative photo of Tony Blair to produce a contrast analog of the Mrs Thatcher illusion, and a bikini to create a full-body analog. This tells us about featural versus configural processing of faces and bodies.

◆ **Wiggly motion looks wonky: a directional anisotropy found with nonlinear motion trajectories**

7 David R Simmons, Jonathan W H Watson (Department of Psychology, University of Glasgow, 58 Hillhead Street, Glasgow G12 8QB, Scotland, UK; e-mail: david@psy.gla.ac.uk)

The bulk of scientific literature on motion perception, except for biological motion and animacy, has employed stimuli moving at constant speeds in straight trajectories. We examined direction discrimination judgments using stimuli consisting of one or more dots moving upwards at a constant net speed of  $5 \text{ deg s}^{-1}$ . Dot motion comprised two components: an 'overall' (straight) motion and a 'wiggle' motion. The wiggle motion was a sinusoidal perturbation in motion direction either side of the overall motion direction. Participants reported whether overall motion direction was clockwise or anticlockwise of vertical in a forced-choice paradigm. An added variable was the wiggle axis, which varied from parallel (dot jumping backwards and forwards along its path), through oblique to orthogonal ('classic' wiggle, like snake motion). An anisotropy was observed, whereby perceived vertical motion for oblique wiggle axes was shifted away from true vertical in opposite directions for left-oblique and right-oblique wiggle axes. Discrimination thresholds were also higher for oblique than for orthogonal or parallel wiggle axes. The threshold data are consistent with a classic oblique effect, but the shift in perceived vertical may relate to motion direction anisotropies with translating bar stimuli (Loffler and Orbach, 2001 *Vision Research* **41** 3677–3692), in that the motion energy of the wiggle combines with the motion energy in the 'true' direction of motion to distort the perceived direction. Whilst these data appear to be explicable in terms of current models of motion perception, this class of stimuli provides an interesting and ecologically plausible new way to test them.

◆ **Motion into and out of the blind spot: Evidence for spatial extrapolation of moving objects**

8 Gerrit W Maus, Romi Nijhawan (Department of Psychology, University of Sussex, Brighton BN1 9QH, UK; e-mail: G.W.Maus@sussex.ac.uk)

The theory of spatial extrapolation proposes that moving objects are perceived in a position shifted forward in the direction of motion to counter perceptual lags due to neural processing delays (Nijhawan, 1994 *Nature* **370** 256–257). Alternatively, it might be that positions are temporally integrated and yield an averaged perceived position (Krekelberg and Lappe, 2000 *Vision Research* **40** 201–215). Here we investigated the final and initial perceived positions of objects moving into and out of the blind spot (BS). First we determined BS boundaries of four observers. Then observers monocularly viewed two bars on circular trajectories, mirrored along the vertical meridian. The bar ipsilateral to the viewing eye moved into the BS, whereas the contralateral bar physically disappeared at one of several preselected positions around the mirrored BS boundary. Observers compared perceived bar offsets in a temporal-order judgment task, effectively measuring the ipsilateral bar's perceived offset position. Similarly, observers compared motion onsets of a bar appearing from inside the BS and its contralateral counterpart. Bars moving into the BS were perceived as disappearing well inside the blind area (shifted forward by  $\sim 1 \text{ deg}$  visual angle,  $\sim 60 \text{ ms}$ ). Filling-in at the BS cannot explain the results, because it requires coherent stimulation at opposing BS borders (Awatramani et al, 2005 *Journal of Neurophysiology* **94** 3314–3324). Temporal integration cannot be invoked to explain visibility of a bar in a position from which there is no retinal input. Therefore the present findings provide evidence for a spatial forward shift of moving objects.

◆ **Perceived and true speeds have the same effect on binocular rivalry**

9 Daniel H Baker, Erich W Graf (School of Psychology, Shackleton Building, University of Southampton, Highfield, Southampton SO17 1BJ, UK; e-mail: d.h.baker@soton.ac.uk)

The relative dominance of gratings engaged in binocular rivalry can be influenced by their surroundings. For drifting stimuli, central gratings opposing the background motion are more dominant (Paffen et al, 2004 *Vision Research* **44** 1635–1639). Such centre-surround stimulus configurations can, however, produce a profound change in perceived speed (Norman et al, 1996 *Perception* **25** 815–830). We used rivaling orthogonal Gabor patches ( $1 \text{ cycle deg}^{-1}$ , 100% contrast,  $\pm 45^\circ$ ), drifting at  $0.5 \text{ deg s}^{-1}$ , embedded in a noise texture drifting at the same speed. Varying the direction of the noise affected the dominance of each grating in the direction expected from previous work. We then used a spatial 2AFC task to match the speed of a noise-embedded Gabor

(standard) with that of a Gabor surrounded by mean luminance (test). As expected, background motion produced substantial changes in perceived speed; at least by a factor of two for all subjects. Lastly, we simulated the context experiment by using gratings (surrounded by mean luminance) moving at different physical speeds, as determined by the matching data. We found the same pattern of dominance as for the context experiment. This suggests that perceived and true speeds influence rivalry in the same manner, perhaps at the same neural locus. Since direction-tuned suppressive and facilitatory surround processes occur in area MT, these findings imply a key role for this brain area in rivalry, through either modulating signals directly or by feedback to earlier visual areas.

◆ **Unique eye of origin attracts attention automatically even when it cannot be detected by forced choice—evidence for the role of the primary visual cortex in bottom-up visual salience**

10 Li Zhaoping (Department of Computer Science, University College London, Gower Street, London WC1E 6BT, UK; e-mail: z.li@ucl.ac.uk)

In a texture of  $22 \times 30$  bars spanning  $34 \text{ deg} \times 46 \text{ deg}$  in visual angle on a black background, observers tried to identify whether a target bar, located randomly at one of 28 texture locations  $15 \text{ deg}$  from the display centre and tilted  $20^\circ$  from background horizontal bars, was clockwise or counterclockwise from horizontal. In randomly interleaved conditions, all bars either had the same (uniform) luminance or different luminance values; and all bars were either presented monocularly to the same eye, or with one being an ocular singleton presented to the other eye. In the dichoptic congruent condition, the ocular singleton was the same as the target; alternatively, in dichoptic incongruence, it was a background bar, equally eccentric and on the opposite lateral side from the target. The bars appeared for 200 ms before being masked by binocularly presented star-shapes of nonuniform luminance. Observers' performances were significantly better in the dichoptic congruent than other dichoptic conditions regardless of whether the bars had uniform luminance, suggesting that the ocular singleton was an exogenous cue attracting attention to the target. Subsequently, in stimuli lacking the tilt singleton and otherwise identical to those described above with bars of nonuniform luminance, the same observers were at chance reporting whether an ocular singleton existed. Since, among all visual areas, the primary visual cortex (V1) has the most monocular cells for eye origin information and is the least associated with awareness, the current findings provide further evidence for V1 as a bottom-up salience map (Li, 2002 *Trends in Cognitive Sciences* 6 9–16).

◆ **Polychromatic colour constancy**

11 Anya Hurlbert, Yazhu Ling, Milena Vurro (Institute of Neuroscience, Newcastle University, Newcastle upon Tyne, UK; e-mail: anya.hurlbert@ncl.ac.uk)

Natural surfaces possess intrinsic chromatic texture. A banana is neither uniformly coloured nor uniformly bright, whether ripe yellow or unripe green. This feature of natural surfaces is not captured by traditional studies of colour perception, which typically employ stimuli of uniform colour and luminance. We consider the effect of surface 'polychromaticity' (Beeckmans, 2004 *Philosophical Psychology* 17 27–44) on colour appearance under changing illumination. Computational models of colour constancy demonstrate that the estimation of the illuminant spectral power distribution improves as the number of distinct surface reflectance samples increases. A single polychromatic surface may provide a number of reflectance samples on its own, and thereby undergo improved colour constancy relative to a surface with a single chromaticity. To quantify and characterise surface chromatic texture, we analysed the surface colour distributions of natural and man-made objects, imaged under artificial daylight illumination with a tristimulus-calibrated camera system. The distribution of within-surface cone contrasts for a given object forms a distinct signature in three-dimensional cone-contrast space. This signature transforms predictably under changes in illumination. Two features of the transformation are theoretically capable of contributing to surface colour constancy: (1) the vector direction of the polychromatic signature tends to remain stable under adaptation to the illumination; and (2) for individual identifiable objects, the chromaticity 'gamut' provides an estimate of the illumination chromaticity.

◆ **Retinal colour coding: maximising image encoding fidelity, minimising metabolic expense**

12 Ben T Vincent, Roland J Baddeley (School of Psychology, University of Dundee, Park Place, Dundee DD1 4HN, Scotland, UK; Department of Experimental Psychology, University of Bristol, 12A Priory Road, Bristol BS8 1TU, UK; e-mail: b.t.vincent@dundee.ac.uk)

The early human visual system has bandpass sensitivity to luminance and there is wide support for the notion that this sensitivity is 'matched' to the properties of natural scenes. However, this notion is not supported for spatio-chromatic sensitivity which is lowpass, as it does not reflect differences between colour and luminance information in natural scenes (Párraga et al, 1998 *Journal of the Optical Society of America, Series A* 15 563–569). High-spatial-frequency

chromatic information present in the world seems to be discarded. This could be because some information is more behaviourally relevant than others (Párraga et al, 2002 *Current Biology* **12** 483–487). We investigated an alternative, that the human visual system maximises coding fidelity of natural images through the optic nerve whilst minimising the metabolic costs incurred. Using similar computational methods as in our previous work (Vincent et al, 2007 *Network* **16**(2/3) 175–190) we predicted the optimal spatio-chromatic sensitivities to encode visual images. Despite some differences, we find striking similarities between our predicted and human spatio-chromatic sensitivities. Namely, 78% of neurons are bandpass-sensitive to luminance, 13% are lowpass-blue-sensitive, and 9% multiplex-lowpass-red/green and bandpass-luminance sensitive. These results provide a renewed basis for thinking that the human visual system is matched to the statistics of the natural environment given the bottleneck of the optic nerve and limited metabolic resources.

◆ **As you write it so you see it: Event-related potential evidence for a stroke-order priming effect in letter recognition**

13 Jim Parkinson, Benjamin J Dyson, Beena Khurana (Department of Psychology, School of Life Sciences, University of Sussex, Brighton BN1 9QH, UK; e-mail: J.M.Parkinson@sussex.ac.uk)

Does the perception of the end-product of an action reflect the temporal sequence of the action that produced it? Human actions have distinct temporal signatures. Letter-writing is a particularly prevalent form of motor action involving the production of strokes in an invariant sequence with a common temporal order. We have previously demonstrated that the temporal order of letter strokes primes letter recognition (Parkinson and Khurana, 2007 *Quarterly Journal of Experimental Psychology* **60** 1265–1274): If letters are presented dynamically as an additive sequence of constituent strokes, letter/non-letter judgments are speeded when the temporal order of the strokes matches that used in writing action. We suggest that this is an influence of learned writing action upon ongoing visual perception of letters. In the current study we investigated neural correlates of this effect by measuring event-related potentials (ERPs) associated with early visual processing, both when engaging in speeded letter/non-letter judgments and when passively viewing the same stimuli under identical presentation conditions. Visual processing was speeded for letters that were produced by action-consistent stroke sequences, measured as latency shifts in early visual components (eg Vibell et al, 2007 *Journal of Cognitive Neuroscience* **19** 109–120). Moreover, visual processing was speeded in the action-consistent sequence prior to it becoming a letter or non-letter, implying visual prediction for letters in an action-consistent sequence. These effects are independent of the letter-judgment task, suggesting that the effect is automatic. Thus, if the dynamic sequence resembles the actions used to produce the letter, perceptual prediction and speeded visual processing occur for the final stimulus.

◆ **The big, the bad, and the ugly: an investigation into the effect of video screen size on visual cognition**

14 Tom Troscianko, Laura Gregory, Kate Hawker, Annelise Bhatt, Gillian Porter, George Lovell, Tim Meese¶ (Department of Experimental Psychology, University of Bristol, 12a Priory Road, Bristol BS8 1TU, UK; ¶ School of Life and Health Sciences, Aston University, Birmingham B4 7ET, UK; e-mail: Tom.Troscianko@bris.ac.uk)

The market for large-format video display units is strong. This suggests that people like watching such large displays—even when the quality of the image is poorer than in the older, but smaller, CRT displays. This study was motivated by a desire to understand how visual cognition is affected by the size of the display. Previous research in this area suffers from confounds of luminance, image quality, and retinal subtense. We therefore planned a series of experiments using projected images of different size but matched for luminance and retinal subtense. Our primary measure was a derived measure of ‘presence’, given by a line bisection task at different points in a movie. The movie used (*The Good, the Bad, and the Ugly* 1967, United Artists) was chosen as being unfamiliar to the (student) subjects, and also having been investigated in an fMRI study (Hasson et al, 2004 *Science* **209** 1631–1641) which showed that different scenes (eg buildings versus faces) activate different areas of visual cortex. In a series of experiments, we established that (a) a larger screen size gives higher presence ratings even when that screen is matched for retinal subtense with another (physically smaller) one; and (b) that there is no screen size by clip type (faces, buildings) interaction, pointing to an overall rather than a scene-specific effect. A recognition-memory experiment showed that the presence results do not predict memory performance. The best candidate for a measure which correlates with rated presence may be arousal, as measured by pupil dilation and reaction time. In summary, the ‘big is good’ effect seems to be mediated by relatively simple processes of attention and cognitive load.

◆ **Characterisation of nob4 retinal ganglion cell responses**

- 15 Donald R Cantrell, Samsoon Inayat, Lawrence H Pinto, John B Troy (Neuroscience Institute, Northwestern University, Evanston, IL 60208, USA; e-mail: j-troy@northwestern.edu)

ERGs of the nob4 mutant mouse lack the b-wave indicating a dysfunction in the ON-pathway of vision. The nob4 mutation causes an amino acid substitution in the mGluR6 receptor. The purpose of this project is to characterise the ON and OFF responses of nob4 mouse retinal ganglion cells (RGCs). This presentation expands upon work reported in Pinto et al, 2007 *Visual Neuroscience* **24** 111–123. RGC responses were recorded from isolated wild type (WT) and nob4 retinas with a multi-electrode array. Peristimulus time histograms were generated in response to a uniform field stimulus consisting of a 1 s light ON period ( $2 \text{ cd m}^{-2}$ ) alternated with a 1 s light OFF period. Cells were then classified as ON, OFF, ON–OFF, OTHER, or NON-RESPONSIVE. The RGC population in WT retina (163 cells) consisted of 21% ON, 15% OFF, 44% ON–OFF, 6% OTHER, and 14% NON-RESPONSIVE cells. The RGC population in the nob4 retina (153 cells) consisted of 1% ON, 26% OFF, 50% ON–OFF, 9% OTHER, and 14% NON-RESPONSIVE. Stimulation with a random checkerboard refreshed at 15 Hz indicates that the cells of the nob4 retina are less responsive to focal stimulation than WT RGCs. In addition, the density of focally responsive OFF centre cells in the nob4 retina is much less than it is in WT. In conclusion, the nob4 RGC population demonstrates a severely compromised ON-response. The nob4 mutant is therefore an excellent animal model in which to study contributions of ON and OFF signals to vision.

◆ **A two-stage process for masking: Linear suppression is more broadly tuned than super-suppression**

- 16 Kirsten L Challinor, Tim S Meese, David J Holmes (School of Life and Health Sciences, Aston University, Birmingham B4 7ET, UK; e-mail: t.s.meese@aston.ac.uk)

In spite of 40 years of research into contrast masking, the number and character of the processes involved remain poorly understood. Meese and Holmes (2002 *Vision Research* **42** 1117–1125) found that a vertical patch of  $1 \text{ cycle deg}^{-1}$  grating is suppressed equally by  $3 \text{ cycle deg}^{-1}$  masks made from an oblique ( $45^\circ$ ) grating with contrast  $C\%$  and a plaid ( $\pm 45^\circ$ ) with component contrasts of  $0.5C\%$ . We call this linear suppression. Derrington and Henning (1989 *Vision Research* **29** 241–246) found that a vertical patch of  $1 \text{ cycle deg}^{-1}$  grating is suppressed more than twice as strongly by a  $1 \text{ cycle deg}^{-1}$  plaid with component contrasts of  $C\%$  than by one of its component gratings with contrast  $C\%$ . We refer to this as super-suppression. To investigate the relation between these two forms of suppression in comparable contrast conditions we measured the bandwidth of masking with plaids and gratings having components contrasts of  $0.5C\%$  and  $C\%$ , respectively, for several target spatial frequencies ( $1$ – $5.2 \text{ cycles deg}^{-1}$ ). We found super-suppression (plaid masking  $\sim 6 \text{ dB}$  greater than grating masking) over a range of  $\pm 0.8$  octaves and  $\pm 40^\circ$  to  $\pm 70^\circ$  in orientation about the target. When the mask spatial frequency was an octave or more higher or lower than the target, grating masking was slightly greater than ( $\sim 2 \text{ dB}$ ) or equal to plaid masking. When the mask and target were  $3 \text{ cycles deg}^{-1}$  and  $1 \text{ cycle deg}^{-1}$ , respectively, we found linear suppression for all mask orientations. We suggest that narrowly tuned super-suppression arises from intra-cortical inhibition involving oriented filters and a profound nonlinearity. This ‘sits on top’ of more broadly tuned linear suppression involving inhibition from (quasi-)isotropic mechanisms.

◆ **The effect of image size on the perception of luminance-defined and contrast-defined motion**

- 17 Claire V Hutchinson, Tim Ledgeway ¶ (School of Psychology, University of Leicester, Henry Wellcome Building, Lancaster Road, Leicester LE1 9HN, UK; ¶ Visual Neuroscience Group, School of Psychology, University of Nottingham, University Park, Nottingham NG7 2RD, UK; e-mail: ch190@le.ac.uk)

We report a preliminary study of the effect of image size on the perception of first-order (luminance-defined) and second-order (contrast-defined) motion. Performance was measured for identifying the drift-direction of  $1 \text{ cycle deg}^{-1}$  luminance-modulated and contrast-modulated dynamic noise drifting at temporal frequencies of 0.5, 2, and 8 Hz. Image size varied over the range 0.125 to  $16 \text{ cycles deg}^{-1}$ . Sensitivity to luminance-defined gratings over a range of image sizes was compared with sensitivity to luminance-modulated noise. The effect of image size on performance for identifying orientation was also measured and was compared with that for motion direction. To quantify the effect of image size on performance, irrespective of absolute sensitivity, modulation sensitivity values were converted to decibels and  $-3 \text{ dB}$  roll-off points calculated. In all cases, sensitivity increased as image size increased. Observers could discriminate motion direction of luminance-defined motion at smaller image sizes than contrast-defined motion:  $-3 \text{ dB}$  roll-offs corresponded to larger image sizes for luminance-modulated than for contrast-modulated dynamic noise. For luminance-defined patterns, roll-offs were unaffected by the presence of a noise carrier and were similar for identifying spatial orientation and motion direction. However, for

contrast modulations, the roll-off for identifying orientation corresponded to a smaller image size than for motion direction. Findings showed that the minimum image size required to support reliable identification of the direction and orientation of moving stimuli is greater for contrast-defined than for luminance-defined motion. Furthermore, whilst the mechanisms that encode orientation and motion direction operate similarly for luminance, for contrast they may be operationally distinct.

◆ **Age and eye movement**

- 18 Andrew J Kolarik, Tom C A Freeman, Tom H Margrain (Cardiff University, Tower Building, Park Place, Cardiff CF10 3AT, Wales, UK; e-mail: kolarika@cardiff.ac.uk)

The accuracy and precision of deliberate and reflexive eye movements were compared between young and old observers. Eye movements were recorded in younger (age: 20–34 years) and older (age: 60–82 years) groups of observers (twenty individuals per group). They were shown moving grating patterns ( $0.6 \text{ cycle deg}^{-1}$ ) for 10 s at speeds of 4.8, 9.6, 19.2, and  $38.4 \text{ deg s}^{-1}$ , and asked either to ‘follow’ the gratings (deliberate pursuit) or ‘stare’ (reflexive nystagmus). Accuracy was assessed with a gain measure (mean eye speed across samples divided by target speed). Precision was defined by partitioning the eye motion variability into drift (standard deviation across slow phase means for each observer) and shake (median across slow phase standard deviations). This is analogous to partitioning the sums-of-squares in ANOVA. Drift reflects long-term variability, ie variability across slow phases. Shake reflects short-term variability, ie variability of the eye movement within each slow phase. We found that eye movements were less accurate in older observers by around 10%–15%, while drift was similar across age groups. Shake increased with stimulus speed, more so in older observers in the deliberate condition. However, no age-related differences in shake were found in the reflexive condition. A similar experiment conducted with random-dot patterns instead of gratings yielded no differences between age groups on any of the measures. This is possibly because features in the dot pattern were easier to fixate and track than the repetitive features of the gratings.

◆ **Luminance contrast is summed across eyes before space**

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Here we assess whether summation of contrast occurs over eyes and space conjointly. Stimuli were sine-wave gratings ( $2.5 \text{ cycles deg}^{-1}$ ) spatially modulated by cosine- and anticosine-phase plaids. This produced patchy gratings where patches were placed at the centres of either the ‘black’ or ‘white’ checks of a notional checkerboard. One eye was presented with pedestal patches in one of these locations (eg ‘black’) and the other eye was presented with pedestal patches in the other locations (eg ‘white’). Contrast increments were presented to one or both eyes (single or dual increments, respectively). Conventional dipper functions were found, but the dual increments were shifted downwards by 4.8 dB. We considered 192 model architectures containing each of the following four elements in all possible orders: (i) linear summation or a MAX operator across eyes, (ii) linear summation or a MAX operator across space, (iii) linear or accelerating contrast transduction, and (iv) additive Gaussian stochastic noise. Formal equivalences reduced this to 48 different models, only 4 of which were consistent with our empirical estimates of summation ratios and slopes of the psychometric functions. 2 of these were rejected by considerations outside the present work. Our preferred model was: linear summation across eyes followed by nonlinear contrast transduction, linear summation across space, and late noise. Results were inconsistent with a MAX operator across eyes but a MAX operator across space remains a viable alternative for the stimulus conditions here. In any case, suprathreshold pooling of contrast across different regions of the retina in different eyes is a property of human vision at threshold and above.

◆ **Neural suppression during accommodation step responses**

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Accommodation is the process by which the eye changes its power to perceive sharp images at different viewing distances. As we do not see blur during this process, visual suppression seems to occur. In the present study we investigated this possibility by measuring and comparing contrast sensitivity during dynamic and static accommodation. Human subjects observed a screen which showed sinusoidal gratings of low, intermediate, and higher spatial frequencies (SFs) and duration of 50 ms. An accommodation stimulus was presented between 1 m and 33 cm in front of the subject. A 2AFC technique and a staircase procedure were used to measure contrast thresholds. Measurements were taken during the dynamic condition at five different time lags



after initiation of an accommodation response, and at their static equivalent. We found that contrast sensitivity for higher SFs was reduced in all our subjects during the rising phase of the accommodation step responses compared with the static equivalents. Low and intermediate SFs did not show significant changes. Preliminary data of VEP recordings for the same experiment support the earlier findings of suppression of higher SFs during dynamic accommodation. We conclude that the visual system may employ suppression during dynamic accommodation. This will prevent the visual system from experiencing sustained masking effects produced by structured patterns of higher spatial frequencies in the visual scene, and will thus provide clear vision when focused on the near accommodation target.

◆ **Perceived direction of motion aftereffect following adaptation to orthogonal retinal motion and smooth pursuit eye movement**

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Adapting separately to retinal motion or pursuit eye movement yields a motion aftereffect (MAE). What happens when adapting simultaneously? Mack et al (1988 *Perception* **18** 649–655) suggested that MAE direction in this case is determined by the motion perceived during adaptation. However, repetitive pursuit is known to adapt extra-retinal mechanisms and so an alternative is that retinal and extra-retinal motion signals combine vectorially during test. To differentiate between these two hypotheses, we measured perceived direction during adaptation and during test. Stimuli consisted of moving random-dot patterns presented centrally (about the pursuit target) or peripherally (10 deg from the target). All stimuli were presented in the dark on a black background. The pursuit target (P) executed a sawtooth wave (period 1 s) consisting of constant upward motion ( $4 \text{ deg s}^{-1}$ ) and abrupt return. The retinal motion of the dot pattern (R) was horizontal ( $4 \text{ deg s}^{-1}$ ). Adaptation could consist of R only, P only, or R + P combined. Experiment 1 replicated Mack et al's effect for both central and peripheral adaptation. In experiment 2 we investigated central adaptation and found that perceived direction during adaptation could not predict perceived direction during test. However, the reported frequency of MAE was low in the R only adaptation condition. In experiment 3, we investigated R + P adaptation in the periphery. Again, we found that perceived direction during adaptation could not predict the perceived direction during test. The results suggest that MAE following simultaneous adaptation is the vectorial combination of adapted retinal and extra-retinal motion signals.

◆ **Seeing light vs dark lines: psychophysical performance is based on separate channels, limited by noise and uncertainty**

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Visual detection performance ( $d'$ ) is usually an accelerating function of stimulus contrast, which could imply a smooth, threshold-like nonlinearity in the sensory response. Alternatively, Pelli (1985 *Journal of the Optical Society of America A* **2** 1508–1532) developed the 'uncertainty model' in which responses were linear with contrast, but the observer was uncertain about which of many noisy channels contained the signal. Such internal uncertainty effectively adds noise to weak signals, and predicts the nonlinear psychometric function. We re-examined these ideas by plotting psychometric functions (as  $z$ -scores) for two observers (SAW, PRM) with high precision. The task was to detect a single, vertical, blurred line at the fixation point, or identify its polarity (light vs dark). Detection of a known polarity was nearly linear for SAW but very nonlinear for PRM. Randomly interleaving light and dark trials reduced performance and rendered it nonlinear for SAW, but had little effect for PRM. This occurred for both single-interval and 2AFC procedures. The whole pattern of results was well predicted by our Monte Carlo simulation of Pelli's model, with only two free parameters. SAW (highly practised) had very low uncertainty. PRM (with little prior practice) had much greater uncertainty, resulting in lower contrast sensitivity, nonlinear performance, and no effect of external (polarity) uncertainty. For SAW, identification was about  $\sqrt{2}$  better than detection, implying statistically independent channels for stimuli of opposite polarity, rather than an opponent (light–dark) channel. These findings strongly suggest that noise and uncertainty, rather than sensory nonlinearity, limit visual detection.

◆ **Misperception of the direction of visually induced illusory self-motion**

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It is generally accepted that the path of visually induced illusory self-motion (vection) is opposite in direction to that of the optokinetic stimulus which produces it. However, in a previous study (Diels and Howarth, 2006 *Aviation, Space and Environmental Medicine* **77** 346), spontaneous

observations by some subjects indicated that random-dot radial optic flow patterns simulating oscillating translation in the fore-and-aft axis were perceived as containing an angular component. Rather than feeling themselves moving back and forth along the line of sight, as one would expect from the stimulus viewed, some subjects reported themselves as being swung on a swing. This is akin to the somatogravic illusion whereby the gravito-inertial force is accepted as the true vertical resulting in an illusory perception of tilt. To assess the robustness of this previously unreported misperception of vection path, eighteen participants were exposed to a radial optic flow pattern simulating oscillating fore-and-aft motion at a frequency of 0.2 Hz. Participants were asked to indicate vection onset time and to describe their motion path throughout a 5 min exposure duration. Despite the absence of angular components in the optic flow patterns, thirteen out of eighteen participants reported feeling themselves as being swung on a swing. It is possible that prior experience, or expectation, may have biased the self-motion percept towards angular self-motion and illustrates the specialisation of the brain's inference mechanisms to 'natural' forms of self-motion (Kersten et al, 2004 *Annual Review of Psychology* **55** 271–304).

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